Preserving the Vasa ship – Research and development of a support structure

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Link to composites

• Wood is a polymer composite

• Composites to support aging structures in cultural heritage

• Sustainable methods to extend lifetime of aging infrastructures

Harrington, 1996
The 17th century warship ”Vasa”
Sank on its maiden voyage 1628
Raised in 1961
1.3 millions visitors/year
1000 tonnes displacement
Aging and creeping...
Background

• 1964: Simple cradle with 8 supports
• 1990: Increasing deformations → more supports
• 2000-: Geodetic measurements: increasing deformation

Need to design an improved support system:
Minimize the risk for collapse and achieve dimensional stability
Position measurements logged since year 2000
Geodetic measurements

Measurements at 400 locations
Creep strain measurements
Average creep strain in elements

\[
\varepsilon_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)
\]

\[
\varepsilon = n_i \varepsilon_{ij} n_j
\]

Maximum principal strain, portside

(van Dijk et al., 2016)
Structure and geometry

Creep: material, beams, joints

FE simulations

Validation: positions motion
Destructive mechanical characterization of Vasa oak

Limited amounts of (in)valuable material

**Static**

Radial compression: ———— Recent oak ———— Vasa oak


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**Creep**

Creep rate > 10 × for Vasa oak

Recent oak

Vasa oak
Micromechanics: cell wall to clear wood

- Microfibril angle
- Density
- PEG/moisture
- Young’s moduli
- Poisson’s ratios
- Shear moduli
- Viscous properties


Effects of the joints on the global deformation

(1) Global FE – Whole ship
(2) Detailed FE model – Joint
Mechanical testing of joints in a wall-section replica

A big test sample...
Construction of 10 tonnes replica
Mechanical testing at KTH Lightweight Structures
Deformation: laser scanning, DSP

Rotational stiffness
Combined bending and compression
In-plane shear stiffness
Comparisons FEM-Experiments → Spring constants
Ship geometry
Division into cross-section and spline interpolation from frame model
Division into zones

A cross-section: inner and outer planks

Different zone of the hull

Top view
• **Solid shell**: hull
• **Shell**: decks, aft side (gallery), beck
• **Beam**: decks, columns, masts, stiffeners
• **Solid**: keel
• **Spring**: joint stiffness
Meshed model (ANSYS)

- Orthotropic solid shell elements
- Shell-beam-spring connections
- Loads from eigenweight and wiring
- Static and generalized to creep
From a validated global **FE model**, provide a tool to bring forth an optimized support structure

**Target:** Relieve highly stressed regions, limit creep deformation
Current support

Concept #1
Concept #2

Comparison of designs:
- displacement
- stress distribution
- reaction forces at the support locations

Internal support structure
Concept 2 better than current support

Less displacement
More symmetric
Concept 2 better than concept 1

Less displacement!

Same trends for maximum stress and reaction loads
Not only Vasa...

- Oseberg and Gokstad viking ships
- HMS Victory
- Cutty Sark
- SS Great Britain
- Fregatten Jylland
- Bremer Cog
- Mary Rose
- Roman ships of Pisa
- Wooden buildings...

Experiences from concrete bridges

(Craig A. Shutt, 2009)
Final remarks

• Composite mechanics useful in design support structure of wooden objects (cultural heritage+)
• A sensitivity study can show which parameters are important than others
• Next step: Verification by static tests
• Future: Control climate to reduce deformation
• Sustainable engineering: Not always build new, also extend lifetime of old